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(54) EARTH FORMATION POROSITY LOG USING MEASUREMENT OF NEUTRON ENERGY SPECTRUM

(71) We, TEXACO DEVELOPMENT COR-
PORATION, a Corporation organized and exist-
ing under the laws of the State of Delaware,
United States of America, of 135 East 42nd
5 Street, New York, New York 10017, United
States of America, do hereby declare the inven-
tion, for which we pray that a patent may be
granted to us, and the method by which it is to
be performed, to be particularly described in
10 and by the following statement:—
. This invention relates to radiological well
logging methods and apparatus for investi-
gating the characteristics of subsurface earth
formations traversed by a borehole, and more
15 particularly, to methods and apparatus for
measuring the porosity of each formations in
the vicinity of a well borehole by means of neu-
tron well logging techniques.
In the search for hydrocarbons beneath the
20 earth's crust one of the parameters which must
be known about an earth formation before
evaluating potential is the fractional volume of
fluid filled pore space, or porosity, present
around the rock grains comprising the earth
25 formation. Several techniques have been deve-
loped in the prior art to measure earth forma-
tion porosity in a borehole environment. One
such technique employs a gamma ray source
and a single, or multiple, detectors to measure
30 the electron density of the earth formation by
gamma ray scattering. This leads to an inferen-
tial measurement of the porosity of the forma-
tions. Another technique employs an acoustic
transmitter and one or more acoustic receivers.
35 The velocity of sound transmission through the
formation from the acoustic transmitter to the
receivers is then measured and this quantity can
be related to the porosity since sound travels
faster in less porous rocks than in fluid filled
40 pore spaces in the earth formations.
A third commercial technique which has
been empoyed in the prior art to measure the
porosity of earth formations employs a neutron
source and either a neutron or gamma ray de-
45 tector sensitive to low energy, or thermalized,
neutron density. Hydrogen is the principal
agent responsible for slowing down neutrons

emitted into an earth formation. Therefore, in a
formation containing a larger amount of hydro-
gen than is present in low porosity formations 50
the neutron distribution is more rapidly slowed
down and is contained in the area of the for-
mation near the source. Hence, the counting
rates in remote thermal neutron sensitive
detectors located several inches or more from 55
the source will be suppressed. In lower porosity
formations which contain little hydrogen, the
source neutrons are able to penetrate further.
Hence, the counting rates in the detector or
detectors are increased. This behaviour may be 60
directly quantified into a measurement of the
porosity via well established procedures.
. All of these commercially employed meth-
ods have generally not proven to be as accurate
as desirable due to diameter irregularities of 65
the borehole wall, variation of the properties
of different borehole fluids, the irregular ce-
ment annulus surrounding the casing in a cased
well borehole, and the properties of different
types of steel casings and formation lithologies 70
which surround the borehole. For example,
the thermal neutron distribution surrounding a
source and detector pair sonde as proposed in
the prior art can be affected by the chlorine
content of the borehole fluid. Similarly, litho- 75
logical properties of the earth formations in the
vicinity of the borehole, such as the boron con-
tent of these formations, can affect the meas-
urement of thermal neutron populations. The
present invention however, rather than relying 80
on a measurement of the thermal neutron pop-
ulation comprises in preferred forms a neutron
measurement of the formation porosity which
utilizes a measure of the epithermal neutron
population at one detector and the fast neutron 85
population at a second detector spaced approxi-
mately the same distance from a neutron
source. The fast neutron population may be
detected directly by means of a fast neutron de-
tector or indirectly by means of an inelastic 90
gamma ray detector. The fast neutron popula-
tion may be background corrected. Special
detectors and other means may be utilized to
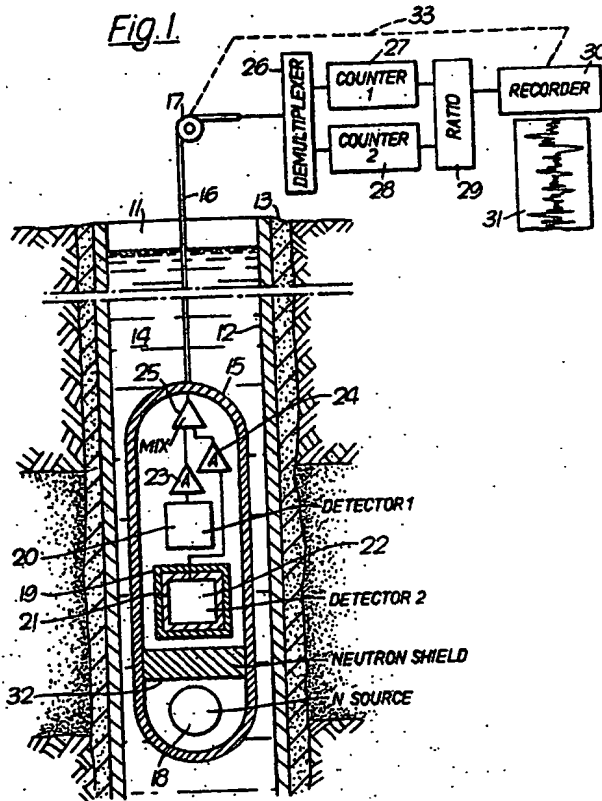effectively discriminate against the detection of

Fig. 1.

present herein, for a programmer of ordinary skill to program such a small general purpose digital computer using a common compiler language such as FORTRAN and utilizing conventional mathematical interpolation procedures to perform this porosity calculation from the calibration charts in the manner described.

A further embodiment of well logging apparatus in accordance with the present invention will now be described, with reference again to Figures 6 to 9. In this further embodiment the first detector 20 of Figure 6, which is a scintillation type fast neutron detector, is replaced by an inelastic scattering gamma ray detector. This detector may comprise a scintillation type detector which is sensitive to the interaction with the scintillator material of gamma rays produced by the inelastic scattering of fast neutrons by the material comprising the earth formations. Such a detector could comprise, for example, a thallium-doped sodium iodide crystal detector which is sensitive to high energy gamma ray interaction. Such scintillation detectors may also be sensitive to high energy gamma radiation produced by the capture of neutrons from the neutron source in earth formations surrounding the well borehole. However, the background correction techniques described above in connection with Figure 6 and 7 can be used to correct for such thermal neutron capture gamma rays. This technique is based on separating the inelastic scattering gamma rays from capture gamma rays by time separation. This is possible because the inelastic gamma rays will generally only exist during a neutron burst, while the capture gamma rays will persist after the neutron burst and thus can be sampled subsequently.

It will be appreciated that the electrical signals from the inelastic gamma ray detector are similar to the electrical signals from the fast neutron detector 20 and are processed by the remainder of the illustrated system in the same manner as described above in connection with Figures 6 to 10. The respective counters 75, 77 and 76 in this embodiment thus provide counts of the number of inelastic scattered gamma rays caused by the fast neutrons present in the vicinity of the detector 20, background counts due to capture gamma rays resulting from lingering thermal neutrons in the vicinity of the detector 20, and epithermal neutrons present in the vicinity of detector 22, in the form of digital counts. It will be appreciated that the detected inelastic gamma rays are representative of the fast neutron population.

WHAT WE CLAIM IS:—

1. A method for determining the porosity of earth formations in the vicinity of a cased well borehole, comprising the steps of:

irradiating the earth formations in the vicinity of the cased well borehole with fast neutrons from a source of fast neutrons passed into the borehole;

generating a signal representative of the fast neutron population present in the well borehole at a location in the borehole spaced from said fast neutron source;

detecting the epithermal neutron population at a location spaced from said neutron source in the borehole and generating a signal representative thereof; and

combining said fast and epithermal neutron population representative signals to derive a measurement signal functionally related to the porosity of the earth formations in the vicinity of the borehole.

2. A method according to claim 1, wherein said fast neutron population location in respect of which said representative signal is generated and said epithermal neutron population detection location are at substantially the same distance from said neutron source in the borehole.

3. A method according to claim 1 or claim 2, wherein said combining step is performed by forming a ratio of said fast neutron and said epithermal neutron representative signals.

4. A method according to claim 3 and further including the step of calibrating said ratio signal according to a predetermined functional relationship to derive a porosity signal quantitatively representative of the porosity of the earth formations in the vicinity of the borehole.

5. A method according to any one of claims 1 to 4, wherein said irradiating step comprises continously irradiating the earth formations with fast neutrons from a continous neutron source.

6. A method according to claim 5, wherein said irradiating step is performed with a chemical type continuous neutron source.

7. A method according to claim 5, wherein said irradiating step is performed with a deuteruim-tritium accelerator type continous neutron source.

8. A method according to any one of claims 5 to 7, wherein said fast neutron representative signal generating step includes detecting fast neutrons by means of a stilbene scintillation detector for fast neutrons, and wherein said detector response to fast neutrons is distinguished from said detector response to gamma rays by pulse shape discrimination.

9. A method according to any one of claims 1 to 4, wherein said irradiating step comprises:

repetitively irradiating the earth formations with relatively short duration bursts of fast neutrons; and wherein said fast neutron representative signal generating step comprises:

detecting, substantially only during each said neutron burst, the fast neutron population present in the well borehole and generating said signal representative thereof.

10. A method according to claim 9 including the steps of:

detecting, substantially during each time interval between said repetitive neutron bursts, the background radiation present at said fast neutron detection location due to lingering